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A COMPARISON BETWEEN INTENSITIES OF A GEOS-A FLASH SEQUENCE AS RECORDED BY PHOTOGRAPHIC AND ELECTRO-OPTICAL TECHNIQUES

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May 1966

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ABSTRACT

A sequence of seven flashes of the GEOS-A satellite was recorded simultaneously by a PC-1000 camera and an electro-optical set up located nearby. Calculations show that the seventh flash should be approximately 6% fainter in brightness than the first flash. Densitometer measurements of the flash images were compared with oscilloscope traces of the same event. The electro-optical recordings appear to represent the calculated individual brightnesses slightly better than the photographic plate.

A COMPARISON BETWEEN INTENSITIES OF A GEOS-A FLASH SEQUENCE AS RECORDED BY PHOTOGRAPHIC AND ELECTRO-OPTICAL TECHNIQUES

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The GEOS-A satellite launched on November 6, 1965, initiated a program which has the following objectives:

a. "Connect geodetic datums to establish one world datum and adjust all local datums to the common center-of-mass of the earth so that positions of geodetic control stations will have a relative accuracy of ±10 meters or better in an earth center-of-mass coordinate system.

b. "Define the structure of the earth's gravitational field to 5 parts in 100,000,000, and refine the locations and magnitudes of large gravity anomalies.

c. "Improve positional accuracies of satellite tracking sites, and calibrate tracking equipment.

d. "Compare and correlate results obtained from the instrumentation and techniques used in order to determine the most accurate and reliable systems."[1]

To aid in accomplishing these tasks, four xenon gas flash lamps are mounted on the earthward side of the satellite. Gravity stabilization causes the lamps to continually point toward the sub-satellite area. An on-board memory monitored by the Applied Physics Laboratory Satellite Control Center activates the lamps to fire when the satellite is visible simultaneously to three or more photographic tracking stations. All firings take place in a sequence of either five or seven flashes which are equally spaced in time, four seconds apart. The beginning flash of a sequence always occurs on an integral minute ±0.4 ms relative to WWV. The

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1. NASA-GSFC Operations Plan 11-65, X-535-65-345, August 1965

flashes are photographed by ballistic cameras and the measured positions of the flashes plus stars on the plates form a basis for the extraction of geodetic data.

The GEOS Photographic Camera

At each of the participating NASA photographic tracking stations, a 40-inch, f/5, focal length camera is employed to photograph the transient outbursts (Figure 1). Micro-flat, backed, glass plates coated with Kodak 038-01 emulsion are used as the recording base. The plates are 8.5 by 7.5 inches in outer dimension while the format on them is 7.1 inches square. Plate scale is 5μ/arc second on the optic axis. The photographed field of view is approximately 10 degrees square. During the photography, the camera is held in a fixed pointing position while the satellite traverses the field of view. Development of the plates is accomplished using Acufine for 18 minutes at 68°F.

Detection of the flash images on the plate is made by laying the plate upon a Bonner-Durchmusterung star chart which is constructed to the same scale as the plate and which covers the same area of the sky. After corresponding stellar images are lined up on plate and chart, the presence of a string of faint images, five or seven in number, is usual evidence of a successful photographic mission.

At this point, the plate is transferred to laboratory personnel charged with the problem of plate measurement.

The Optical Systems Branch Timing Experiment

In March 1966, the Optical Systems Branch of the Goddard Space Flight Center conducted a timing experiment with the GEOS-A satellite. The experiment took place at the Goddard Optical Research Facility which is also a participating photographic station for the GEOS project. The objective of the experiment was to accurately determine the following:

a. The times when a sequence of flashes on the GEOS-A satellite begin.

b. The interval in time between each flash of a sequence.

c. The duration of each flash in a sequence.

The apparatus used to fulfill the above objectives was made up of electro-optical equipment, Figure 2, which consisted of the following:

1. A 16-inch reflector telescope mounted on a Nike-Ajax mount which was tape driven to track the satellite during several of its passes across the horizon of the Goddard Optical Research Facility.

2. A photomultiplier tube, the EMI 9558A, with an S-20 response, installed with its cathode surface of 1.5 inch diameter near the focal plane of the 16-inch telescope.

3. An oscilloscope located within 15 cable feet of the photomultiplier tube and having a Polaroid camera integral with it to photograph the undistorted flash signals.

4. An FR-600 magnetic tape recorder to produce a visual record on paper tape of various time signals employed plus the actual flash sequences.

A complete description of the above experiment has been published previously.[2]

After the above experiment was successfully concluded, it was thought that it would be informative to compare the individual relative intensities of the flashes in a sequence as obtained by the electro-optical equipment and the PC-100 camera which was situated 200 feet northeast of the Nike-Ajax mount.

The Flash Sequence Observed By Telescope and Camera

On the morning of March 9, 1966, the flash sequence on GEOS-A which began at $07^h\ 48^m$ Greenwich mean time was recorded simultaneously by the electro-optical apparatus and the PC-1000 camera at the Goddard Optical Research Facility. During this sequence, all four lamps on the satellite flashed. Local weather conditions during the sequence were good. The sky was clear, seeing was condition 2 meaning 4th magnitude stars were clearly visible to the naked eye. Ambient temperature was $18^\circ F$ and ambient pressure was 30.65 inches. Relative humidity averaged 45%. A 92% illuminated moon was in the southwest at $07^h\ 48^m$.

The satellite began its flashes at a predicted altitude of $40^\circ\!.1$ and an azimuth of $49^\circ\!.9$. Its seventh flash occured at an approximate altitude of $37^\circ\!.9$ and an azimuth of $49^\circ\!.1$. The predicted slant range distance at $07^h\ 48^m$ was 3031 km. and at $07^h\ 49^m$ it was 3240 km., making its interpolated distance at the seventh flash about 3115 km. These figures indicate that because of slant range change, the last flash in the sequence should be approximately 5% fainter than the first whereas because of increased atmospheric absorption

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[2]"A Timing Experiment Using the GEOS Satellite Optical Beacon" by J. E. Moye March 1966, X-524-66-149, Goddard Space Flight Center, Greenbelt, Maryland

the last flash should be fainter by $<$ 0.02 magnitudes or $\sim$ 1% in brightness. The combined effect makes the expected brightness of the last flash approximately 6% fainter than the first. Two assumptions made here are that

a. The angle between the flash lamp pointing and the camera changes very little in the 24 seconds of the flash sequence.

b. The change in intensity of the individual beams traversing different optical paths in the camera amounts to $<$ 1%.

Appearance of Photographic Plate

The specific photographic plate selected to use in this comparison was chosen because of the following reasons:

a. The developed plate was unusually clean.

b. The area of the sky through which the satellite traveled during its flash sequence was devoid of clouds.

c. All flash images on the plate were reasonably close to the optic axis.

The measured distances on the plate from its center to each of the flash images is tabulated in Table I.

TABLE I

Flash Number	Distance - Center to Image
1	$\frac{22}{32}$ inches
2	$\frac{14}{32}$ inches
3	$\frac{6}{32}$ inches
4	$\frac{9}{32}$ inches
5	$\frac{16}{32}$ inches
6	$\frac{24}{32}$ inches
7	$\frac{32}{32}$ inches

The measured diameters of the individual images on the plates are listed in Table II.

TABLE II

Flash Number	Distance - Center to Image
1	48 microns
2	38 microns
3	46 microns
4	57 microns
5	48 microns
6	55 microns
7	49 microns

The seven images lie on an almost straight line and the distance between the first and last image is 1.57 inches.

The Density Measurements

Density measurements were made with the Automatic Integrating Microdensitometer, MK3C, manufactured by Joyce Loeble Company. All measurements were taken by using the slit diaphram at a setting of 10 microns wide by 50 microns long. An optical system picked up an area on the plate approximately 1/20 inch in diameter and projected it onto a small screen in front of the operator. Using an effective magnification of 29, the operator then ran the slit centrally over each image. An automatic tape recorder inked out the densities of the individual images and the plate background, Figure 3. Images 1, 3, 4, and 7 were scanned twice.

Table III lists the difference in inches above the plate background level that each image measured. The instrument had been calibrated so that a scale reading change of one inch on the recorded graph was approximately a 1.3X change in intensity over the range that was measured.

TABLE III

Flash Number	Inches Above Background
1	1.85
2	1.60
3	1.45
4	1.80
5	0.90
6	1.30
7	1.20

As seen from Table III, the difference in intensity between the first and last images is approximately 18% whereas it had been calculated to be 6%. The measurements show a general downward trend in intensity from first to last image but exceed the computed values. One possible reason for this is the well known fact that different areas on a photographic plate do not respond equally to stimuli of the same intensity or duration.

The Electro-Optical Recordings

Figure 4 represents the photographic recordings of the seven flashes obtained by the electro-optical apparatus. In these recordings, flash number 7 is clearly the faintest flash of all while the brightest appears to be either number 5 or 1. Since the response of the photomultiplier tube was linear over the range covered, it appears that the first flash is approximately 10% brighter than the last flash.

Results

Comparison of the seven measured density profiles with the seven oscilloscope tracings does not show an exact flash to flash correspondence. The major facts brought out by the two techniques are as follows:

a. The photographic technique definitely shows image one to be the brightest.

b. The electro-optical technique definitely shows the last image to be the faintest.

c. Both techniques indicate a gradual decrease in brightness of the flashes proceeding from the first to the last.

d. Both techniques show the fourth flash to be brighter than the third.

e. There is a sharp disagreement over the brightness of the fifth flash, with the electro-optic apparatus showing it to increase whereas the photographic reveals it as the faintest of all.

ACKNOWLEDGMENT

The author wishes to thank Mr. Dennis Evans of the Astrophysics Branch for measuring the image densities and Mr. John Moye of the Optical Systems Branch for supplying photographs of the oscilloscope tracings.

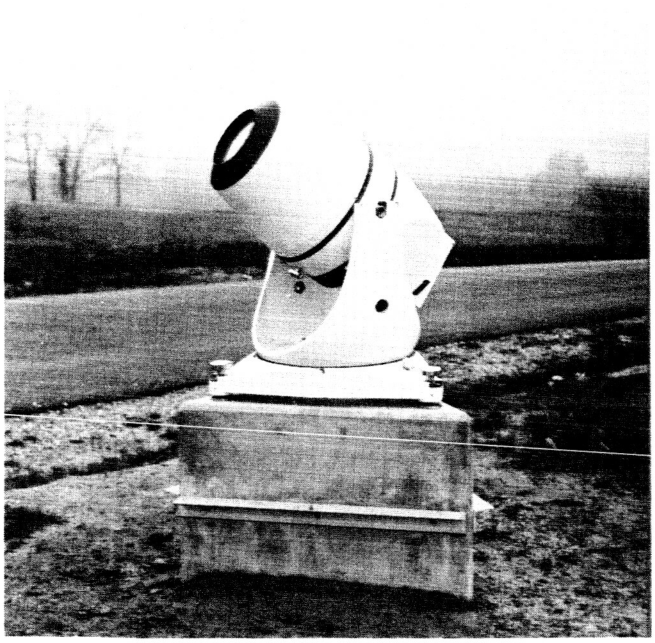


FIGURE 1

THE PC-1000 CAMERA USED TO PHOTOGRAPH THE GEOS-A FLASH SEQUENCES.

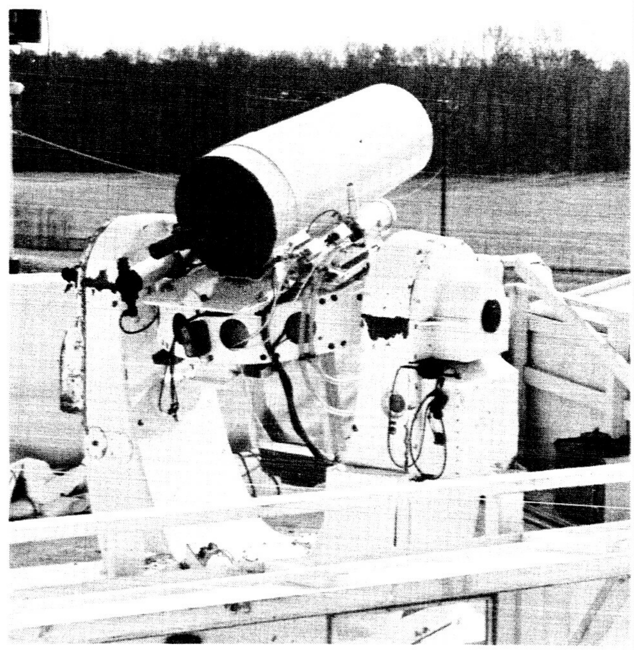
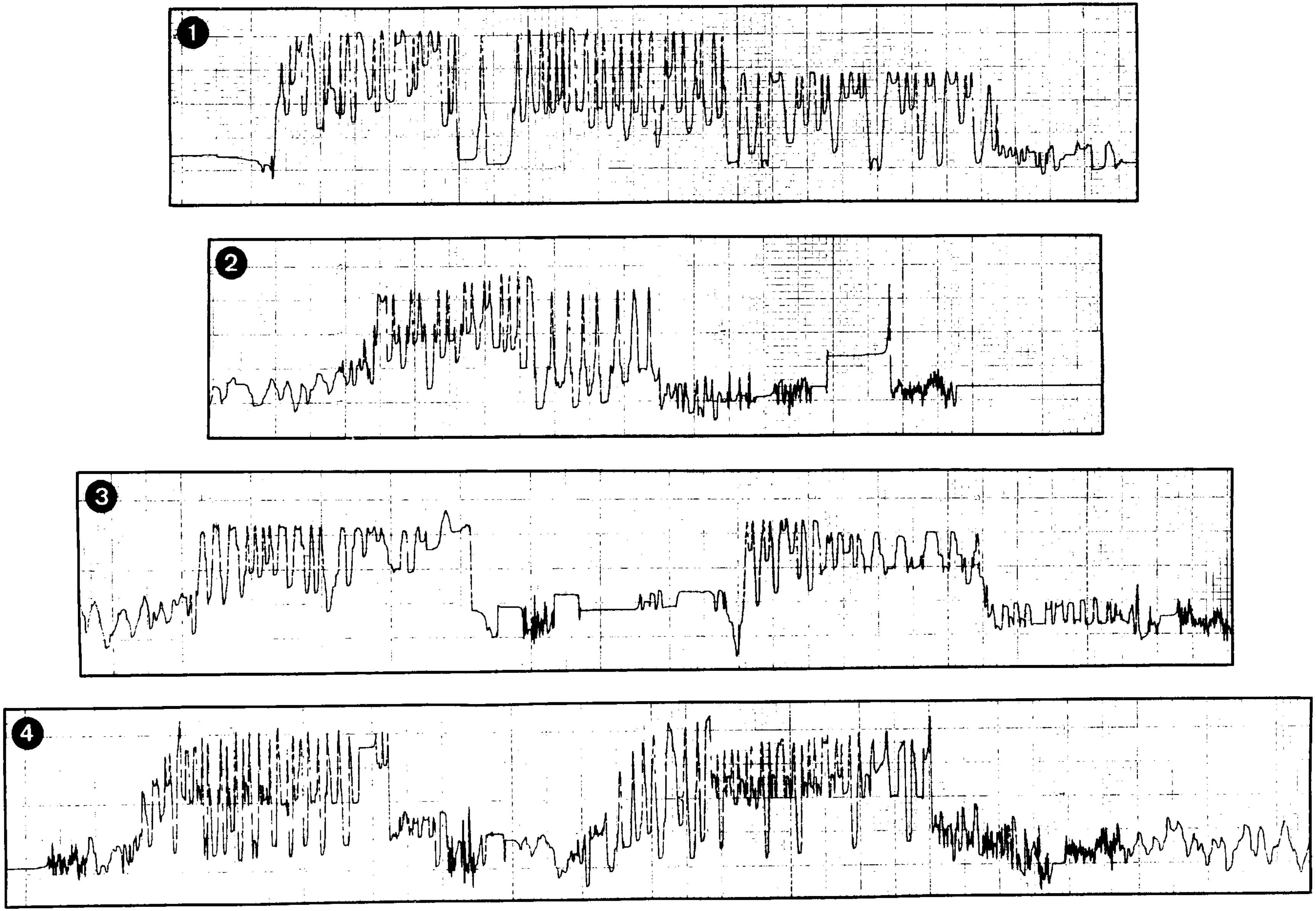


FIGURE 2

THE ELECTRO-OPTICAL APPARATUS USED TO OBTAIN OSCILLOSCOPE TRACINGS OF THE GEOS-A FLASH SEQUENCES.


1
2
3
4

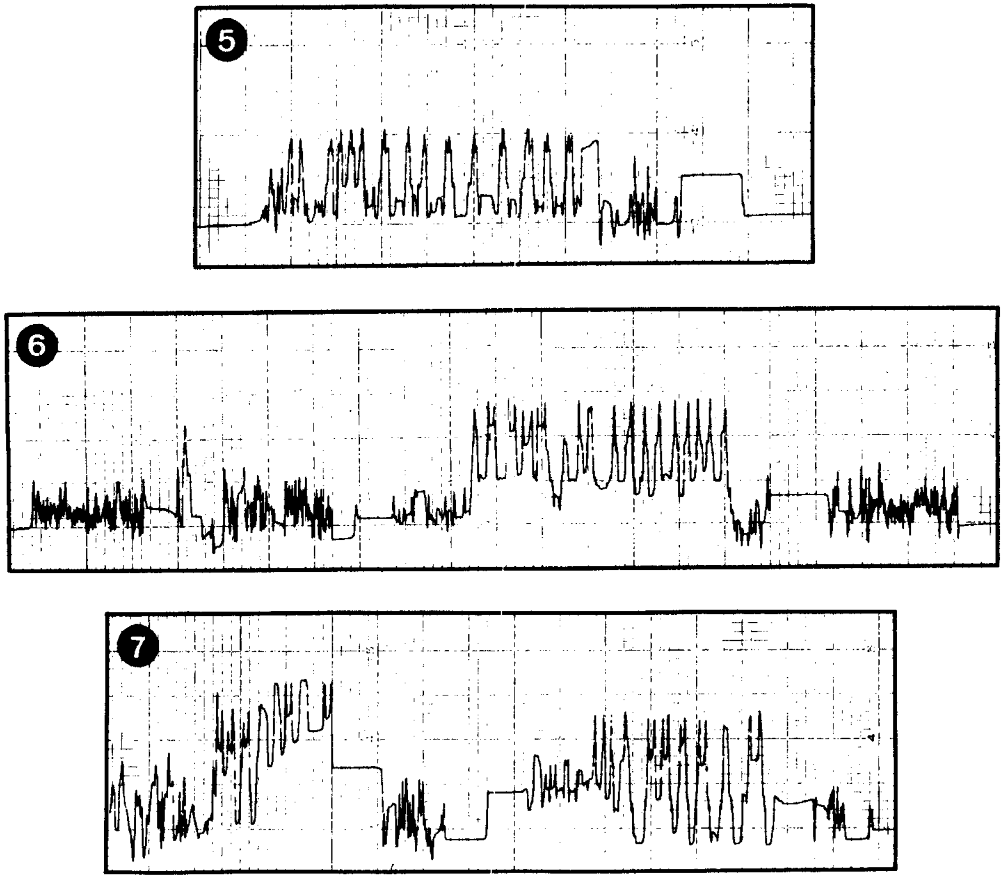


FIGURE 3
THE MICRODENSITOMETER RECORDINGS OF THE GEOS-A FLASH SEQUENCE OF MARCH 9, 1966 BEGINNING AT $07^{h}\ 48^{m}\ 00^{s}$ U.T.

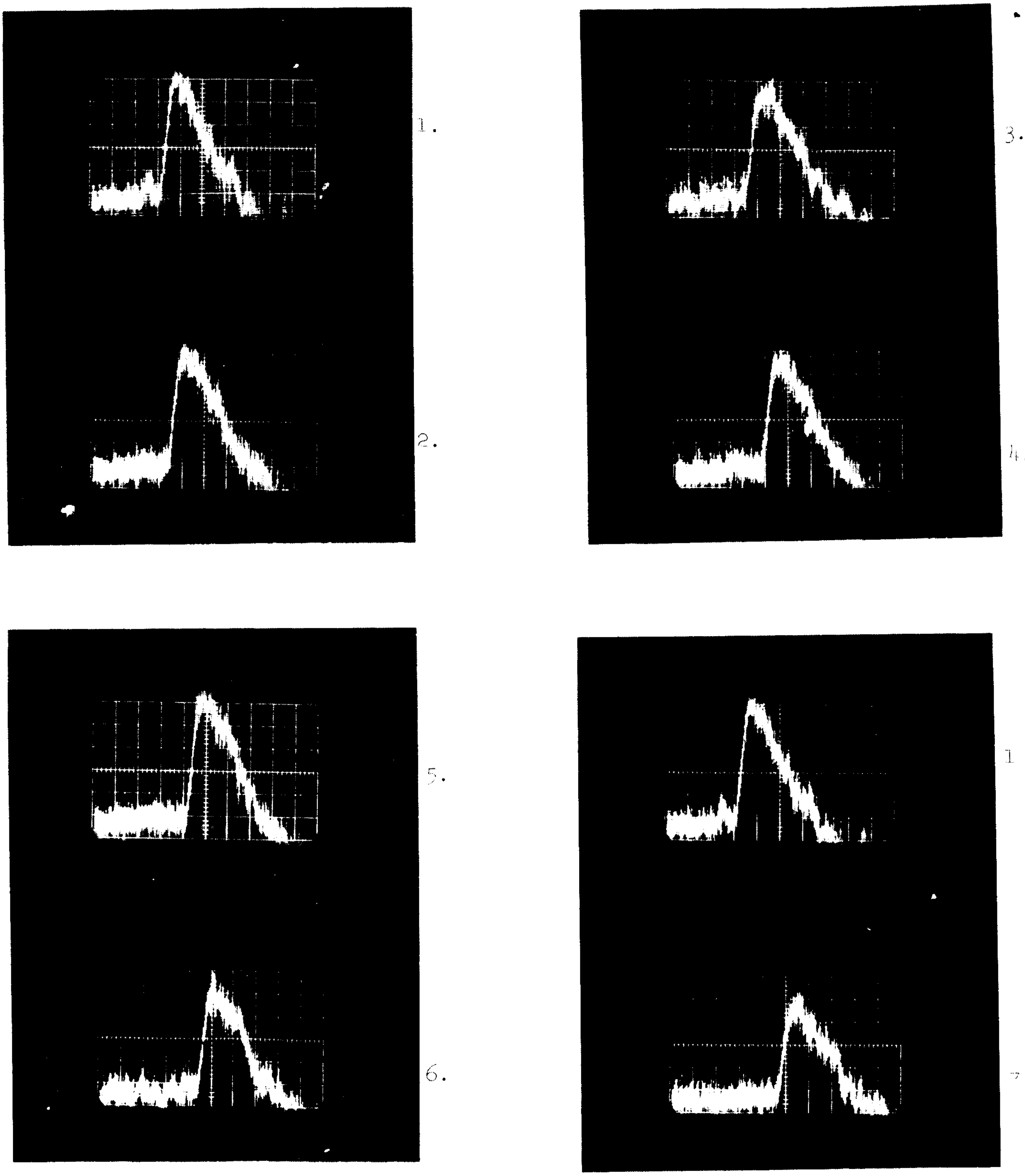


FIGURE 4 . OSCILLOSCOPE TRACINGS OF THE GEOS-A FLASH SEQUENCE BEGINNING AT $07^h\ 48^m\ 00^s$ U.T. ON MARCH 9, 1966. EARLIER TIME IS AT THE LEFT.